1-MHz, 3.3-V, High-Efficiency Synchronous Buck Converter With TPS43000 PWM Controller

Sophie Chen *System Power*

ABSTRACT

The TPS43000 is a high-frequency, voltage-mode, synchronous PWM controller that can be flexibly used in buck, boost, buck-boost, and SEPIC topologies. This reference design explains the design procedure of a step-down application from 4.5 V to 8.5 V down to 3.3 V with the TPS43000 PWM controller.

Contents

1 Introduction

This full-featured controller is designed to drive a pair of external MOSFETs (N or P) and can be used with a wide range of output voltages and power levels. It can be widely used in networking equipment, servers, PDAs, cellular phones, and telecommunication applications. The datasheet describes the functionalities of the controller in more detail.

A schematic of this board is shown in Figure 1. Recommended parts list is provided in Table 1. The layout of the PCB board is shown in Figure 6.

The specification for this board is as follows:

- 4.5 V $\leq V_{IN} \leq$ 8.5 V
- V_{OUT} = 3.3 V
- 50 mA $\leq I_{OUT} \leq$ 2 A, enters PFM at 200 mA, nominal current is 1 A
- Switching frequency, f_S = 1 MHz
- Ripple = 1%
- Efficiency at nominal load > 90%

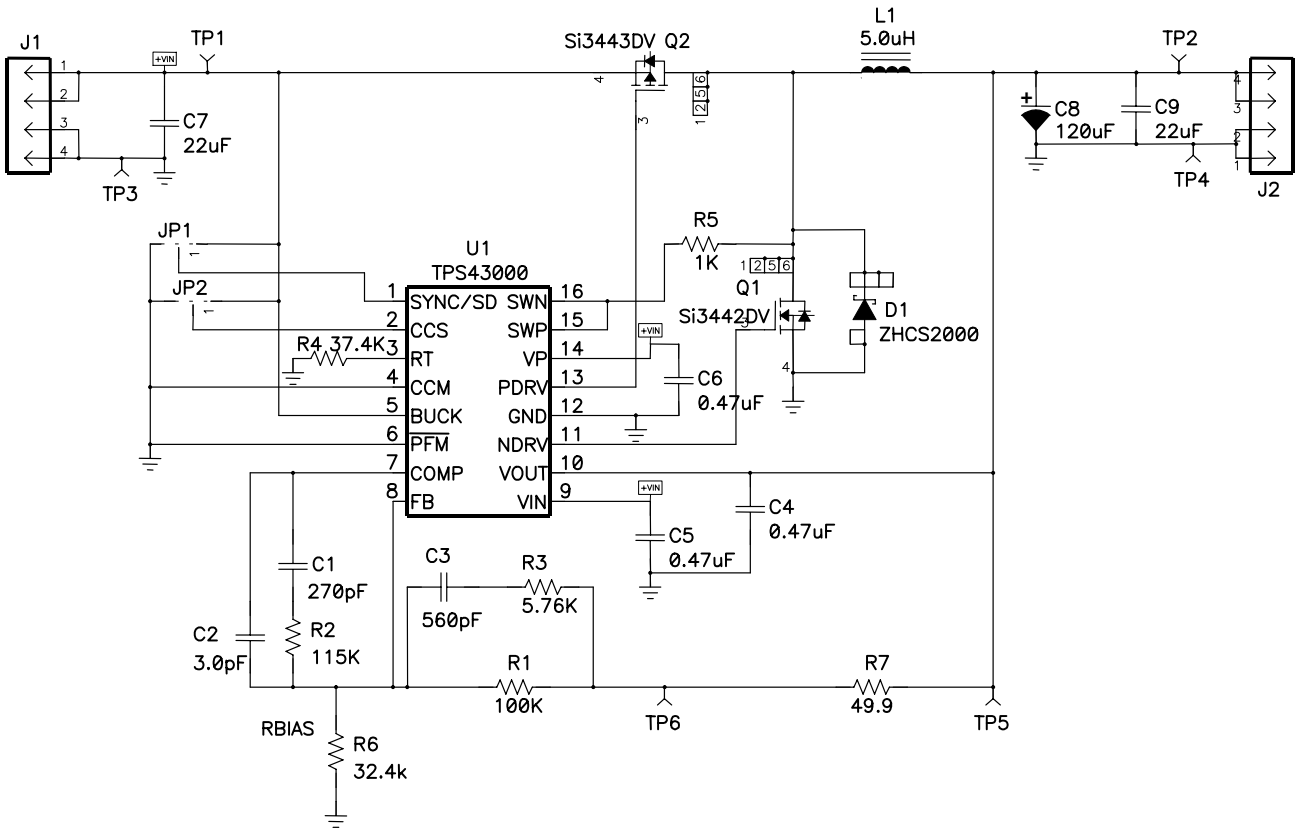

Figure 1. PMP143 Schematic

2 Design Procedure

2.1 Frequency Setting

The TPS43000 can operate either in constant frequency, or in an automatic PFM mode. In the automatic PFM mode, the controller goes to sleep when the inductor current goes discontinuous, and wakes up when the output voltage has fallen by 2%. This pulse skipping can decrease gate-drive losses and significantly improve the efficiency at light load. (Refer to the TPS43000 Data Sheet, TI Literature No. SLUS489 for more information.)The converter is designed to operate at fixed 1 MHz above 0.2 A. The PFM mode is used when the load decreases to below 0.2 A.

A resistor, R4, connected from the RT pin to ground, programs the oscillator frequency. The approximate operating frequency is calculated in equation (1).

$$f\,(\text{MHz}) = \frac{38}{\text{R4}\ (\text{k}\Omega)} \tag{1}$$

R4 = 37.4 kΩ is chosen for 1-MHz operation.

2.2 Inductance Value

The inductance value can be calculated as shown in equation (2).

$$L_{(min)} = \frac{V_{OUT}}{f \times I_{RIPPLE}} \times \left(1 - \frac{V_{OUT}}{V_{IN(max)}}\right) \quad (2)$$

I_{RIPPLE} is the ripple current flowing through the inductor, which affects the output voltage ripple and core losses. According to the specification, the converter enters PFM mode at 200 mA, so the desired ripple current it 0.4 A. Based on this and the 1-MHz operating frequency, the inductance value is calculated at 5.0 μH.

2.3 Input and Output Capacitors

The output capacitance and required ESR can be calculated by equations (3) and (4).

$$C_{OUTPUT\ (min)} = \frac{I_{RIPPLE}}{8 \times f \times V_{RIPPLE}} \quad (3)$$

$$ESR_{OUT} = \frac{V_{RIPPLE}}{I_{RIPPLE}} \quad (4)$$

With 1% output voltage ripple, the capacitance required is at least 1.5 μF and its ESR should be less than 81.7 mΩ. A Panasonic 4-V, 120-μF capacitor is chosen with an ESR of 18 mΩ.

The required input capacitance is calculated in equation (5). The calculated value is approximately 20 μF. A 22-μF ceramic capacitor is used in order to handle the ripple current.

$$C_{IN\ (min)} = I_{OUT\ (max)} \times D_{max)} \times \frac{T_S}{V_{IN\ (ripple)}} \quad (5)$$

2.4 Compensation Design

The TPS43000 uses voltage-mode control. R1, R2, and R3 along with C1, C2 and C3, form a Type III compensator network. The L-C frequency of the power stage, f_C is approximately 6.5 kHz and the ESR zero is around 73.7 kHz, as shown in Figure 2. The overall crossover frequency, f_{0db} , is chosen at 50 kHz for reasonable transient response and stability. The two zeros, f_{Z1} and f_{Z2} from the compensator are set at 0.5 f_C and f_C separately. The two poles f_{P1} and f_{P2} are set at ESR zero and 0.5 f. The frequency of poles and zeros are defined by the following equations:

$$f_{Z1} = \frac{1}{2\pi \times R2 \times C1}$$

$$f_{Z2} \approx \frac{1}{2\pi \times R1 \times C3} \quad \text{assuming } R1 \gg R3$$

$$f_{P1} = \frac{1}{2\pi \times R3 \times C3}$$

$$f_{P2} \approx \frac{1}{2\pi \times R2 \times C2} \quad \text{assuming } C1 \gg C2$$

The compensator values are calculated as follows:

C1 = 270 pF, C2 = 3.0 pF, C3 = 560 pF, R1 = 100 kΩ, R2 = 115 kΩ, and R3 = 5.76 kΩ.

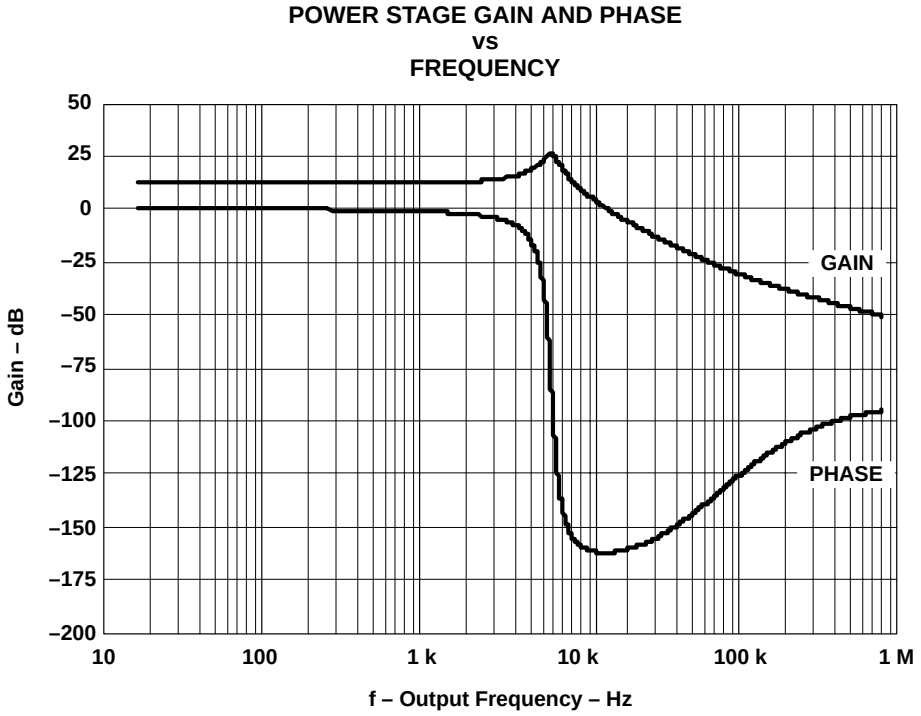

Figure 2.

2.5 MOSFETs and Diode

For a 3.3-V output voltage, the lower the $R_{DS(on)}$ of the MOSFET, the higher the efficiency. Also, considering the 1-MHz switching frequency, Si3442DV ($R_{DS(on)}$ = 65 mΩ) and Si3443DV ($R_{DS(on)}$ = 70 mΩ) are chosen for fast switching speed.

2.6 Current Limiting

Two types of current limiting can be selected from the controller. Detailed information is available in the datasheet (TI Literature No. SLUS489). A jumper, JP2, is used to choose different current limiting. By tying the CCS pin to VIN, the controller enters pulse-by-pulse current limiting and the current-limiting threshold is calculated by equation (6):

$$I_{MAX\,(p-p)} = \frac{150\ mV}{R_{DS(on)}} \tag{6}$$

in which $R_{DS(on)}$ is the on-resistance of Q2. In this design, the threshold is approximately 2.3 A.

By tying the CCS pin to ground, the controller enters hiccup-mode overcurrent limiting . The current-limiting threshold is calculated in equation (7). The threshold in this case is approximately 3.8 A.

$$I_{MAX\,(hu)} = \frac{250\ mV}{R_{DS(on)}} \tag{7}$$

2.7 Voltage Sense Resistor

R1 and R6 operate as the output voltage divider. The internal reference voltage is 0.8 V. The relationship between the output voltage and divider is described in equation (8).

$$\frac{V_{REF}}{R6} = \frac{V_{OUT}}{R1 + R6} \tag{8}$$

With an R1 value of 100 kΩ and 3.3-V voltage regulation, R6 is calculated at 32.4 kΩ.

3 Test Results

3.1 Efficiency Curves

Efficiency tested at different loads and input voltages is shown in Figure 4. The maximum efficiency is as high as 94% at 0.5 A output. The light-load efficiency is much improved due to the PFM operation mode.

3.2 Typical Operation Waveform

Typical operating waveforms are shown in Figure 5 with V_{IN} = 4.5 V and I_{OUT} = 2 A.

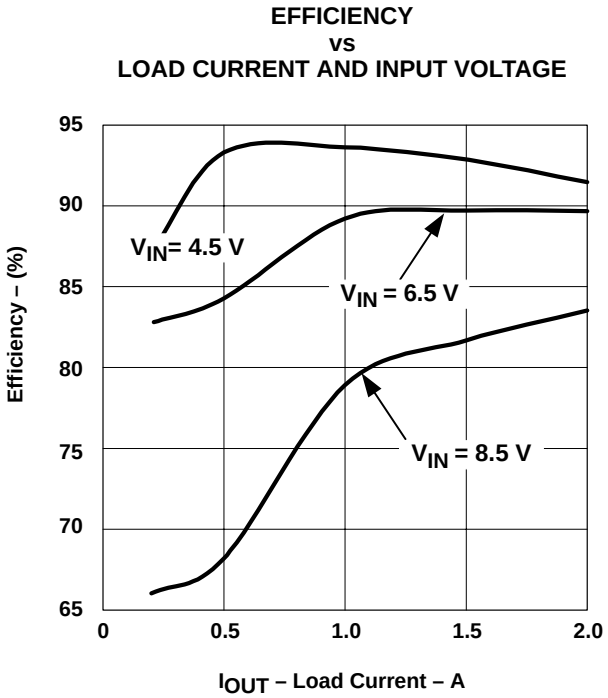

Figure 3.

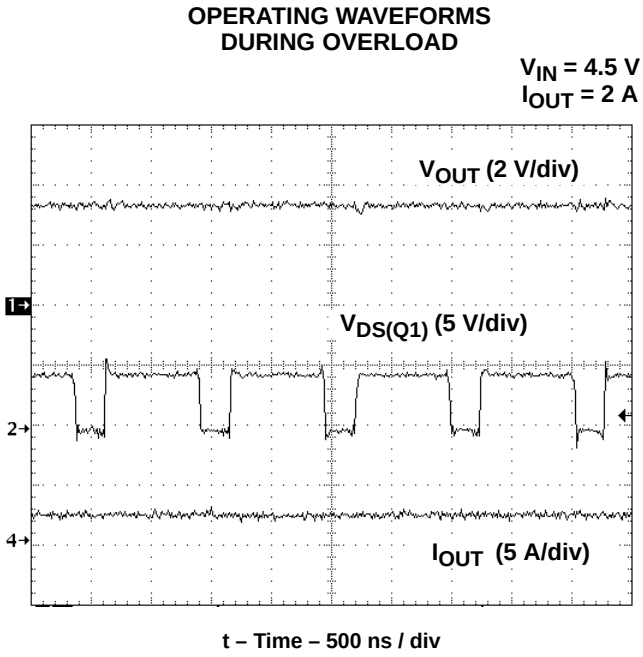

Figure 4.

3.3 Output Ripple Voltage and Transient Response

The output ripple is approximately 28.8 mV peak-to-peak with a 1.5 A output and is shown in Figure 4. Figure 5 shows load changes from 0.5 A to 1.5 A, where the overshooting voltage is approximately 10 mV.

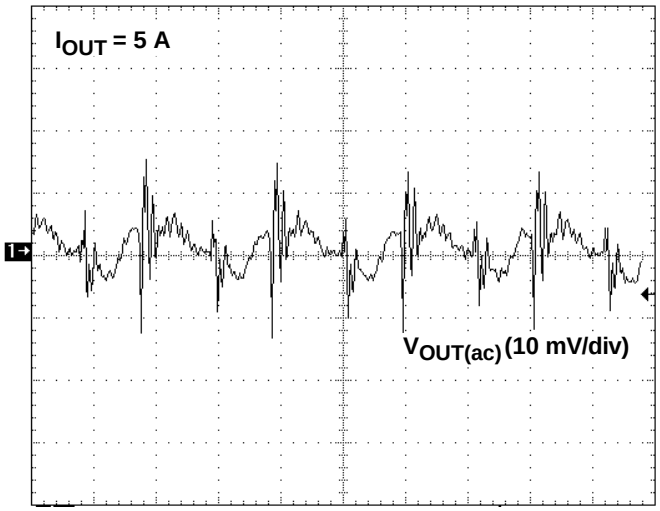

Figure 5. Output Ripple

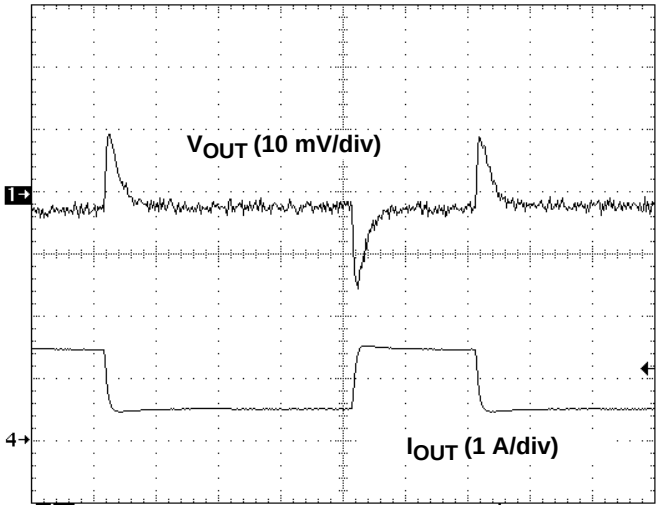

Figure 6. Transient Response

4 PCB Layout

Figures 8 and 9 show the PCB layout . All components are on the top side of the board. The bottom side of the board is the ground plane.

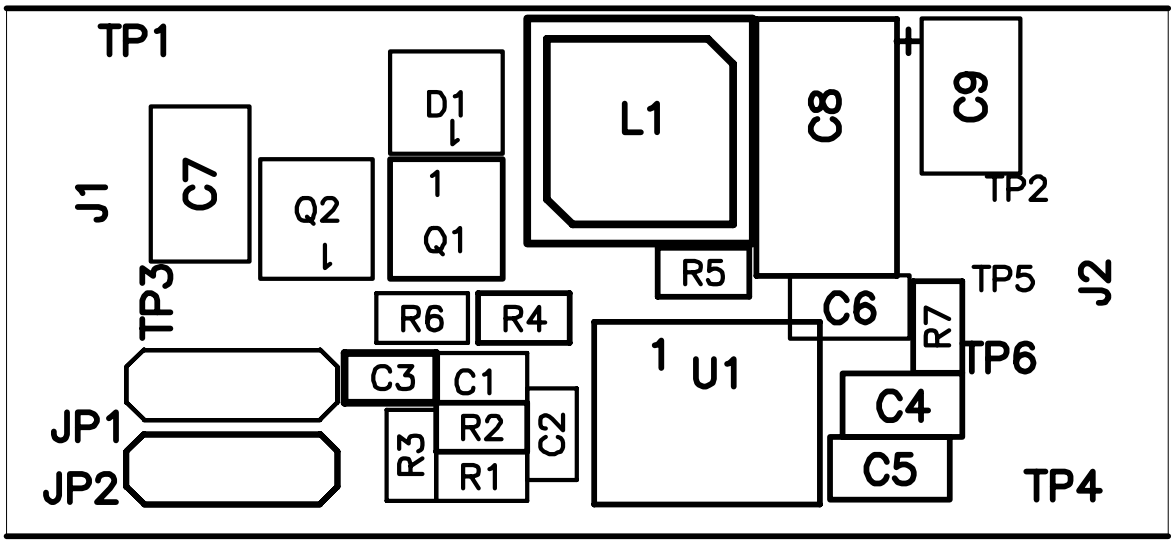

Figure 7. Components Placement

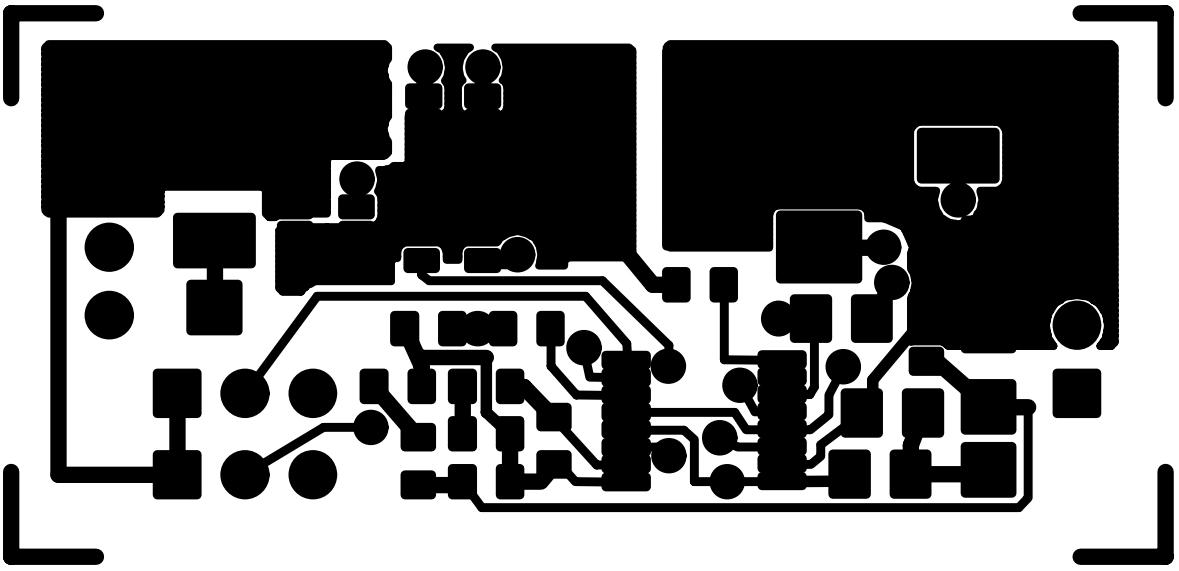

Figure 8. Top Side

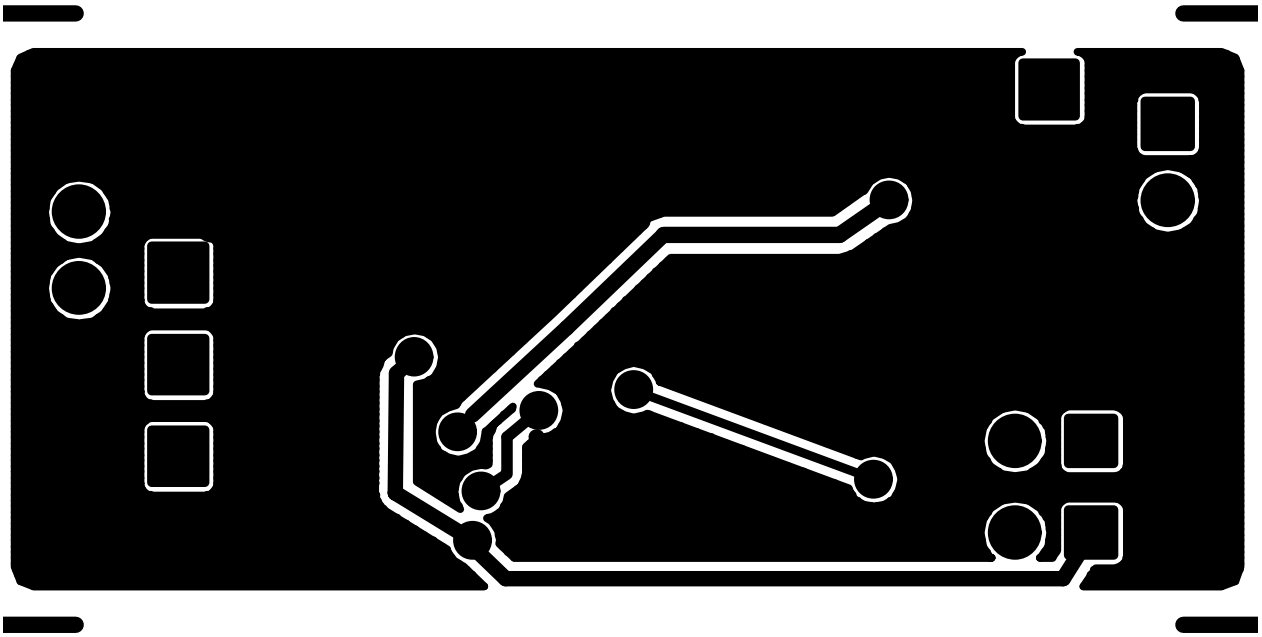

Figure 9. Bottom Side

5 List of Materials

Table 1 lists the board components and their values, which can be modified to meet the application requirements.

Table 1. Bill of Materials

REFERENCE DESIGNATOR	QTY	PART NUMBER	DESCRIPTION	MFG	SIZE
C1	1	GRM1885C1H271J K	Capacitor, ceramic, 270 pF, 50 V, COG, 5%	Murata	603
C2	1	GRM1885C1H3R0J K	Capacitor, ceramic, 3 pF, 50 V, COG, 5%	Murata	603
C3	1	GRM188R71H561J K	Capacitor, ceramic, 560 pF, 50 V, 5%	Murata	603
C4,C5,C6	3	GRM219R71C474K K	Capacitor, ceramic, 0.47 μF, 16 V, X7R, 10%	Murata	805
C7,C9	2	JMK325BJ226MM	Capacitor, ceramic, 22 μF, 6.3 V, 20%	Taiyo-Yuden	1210
C8	1	EEFUD0D121R	Capacitor, 120 μF, 4.0 V, 18 mΩ, 20%	Panasonic	7343 (D)
D1	1	ZHCS2000	Diode, schottky, 2 A, 40 V	Zetex	SOT23–6
J1,J2	2	PTC36SAAN	Header, 4-pin, 100 mil spacing, (36-pin strip)	Sullins	0.100 x 4”
L1	1	CDRH6D38	Inductor, SMT, 5.0 μH, 2.9 A, 24 mΩ	Sumida	6.7 X 6.7 mm
R1	1	Std	Resistor, chip, 100 kΩ, 1/16-W, 1%	Std	603
R2	1	Std	Resistor, chip, 115 kΩ, 1/16-W, 1%	Std	603
R3	1	Std	Resistor, chip, 5.76 kΩ, 1/16–W, 1%	Std	603
R4	1	Std	Resistor, chip, 37.4 kΩ, 1/16-W, 1%	Std	603
R5	1	Std	Resistor, chip, 1 kΩ, 1/16-W, 1%	Std	603
R6	1	Std	Resistor, chip, 32.4 kΩ, 1/16-W, 1%	Std	603
R7	1	Std	Resistor, chip, 49.9 Ω, 1/16-W, 1%	Std	603
Q1*	1	Si3442DV	MOSFET, N–channel, 2.5-V_{GS}, 4 A, 70 mΩ	Siliconix	TSOP–6
Q2*	1	Si3443DV	MOSFET, P-channel, 2.5-V_{GS}, 4.4 A, 90 mΩ	Siliconix	TSOP–6
U1*	1	TPS43000PW	Multi–topology high-frequency PWM controller	Texas Instruments	TSSOP–16
TP1,TP2,TP5,	3	240–333	Test point, red, 1 mm	Farnell	0.038”
TP3,TP4,TP6	3	240–333	Test point, black, 1 mm	Farnell	0.038”
N/A	1	PMP143	Printed circuit board, FR4, 0.032, SMOBC	any	

NOTE: * All components can not be substituted.

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third–party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Mailing Address:

Texas Instruments
Post Office Box 655303
Dallas, Texas 75265